Are gamers better at anticipatory responding and anticipatory response inhibition?

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Statement of Sources

I declare that this report is my own original work and that contributions of others have been duly acknowledged.

Signed: ________________________ Date: 30/10/2018

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Abstract

Response inhibition is an executive modulating ability that supresses responses that are no longer relevant or required. The role of inhibition has been extensively examined in literature that proposes the notion that pathological gamers are comparable to those who suffer from other behavioural addictions such as substance abuse and gambling. This pathological framework argues that pathological gamers have underlying components of impulsivity and reduced inhibitory ability. On the other hand, there is an approach, defined as the adaptive framework, that argues response inhibition can be learned and improved like other cognitive abilities such and working memory and processing speeds. This thesis investigated the gaming-inhibition dyad to determine if the results would fit the pathological or the adaptive framework. Thirty-nine participants aged 19-69 (M=28.80, SD=13.80, 13 females) completed Dickman's (1990) impulsivity inventory and a questionnaire measuring their gaming experience A novel, gamified anticipatory response inhibition stop-signal task, "ARI's staff", was developed to investigate participants stop-signal reaction times (SSRT). The results revealed a negative correlation between SSRT and videogame experience, implying that those with more game experience had faster inhibitory abilities. Furthermore, those with more gaming experience also responded more precisely. Impulsive underpinnings as a possible mediator for the gaming-inhibition was not found. The findings here predominantly support the adaptive framework; however, it is cautioned that the postulates of the pathological framework not be entirely dismissed.

This thesis will investigate whether videogame experience has an effect on one's anticipatory responding and inhibition. The literature on the videogaming-inhibition dyad is inconsistent—one approach postulates an inhibition deficit due to manifesting the six components of addiction (Griffiths, 2005) and underlying components of impulsivity (Bari & Robbins, 2013) while the other approach claims that inhibition part of a host of cognitive abilities that can be learned, trained and improved (Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009). There are several confounds with how researchers have traditionally measured response inhibition and I outline the justification of utilizing a novel, gamified stop-signal task.

Response Inhibition, the Stop-Signal Paradigm and the Independent Race Model

From stopping yourself grabbing a hot pan you just dropped to military personnel ceasing fire when civilians/friendlies are in the line of sight, response inhibition refers to a modulating ability that supresses responses that are no longer appropriate or required (Bari & Robbins, 2013). This hallmark of executive control is represented in the prefrontal cortex (Coxon, Stinear, & Byblow, 2007). When the areas of the brain responsible for motor movement are engaged in preparation of a response, the prefrontal cortex exerts a "top-down" influence—allowing us to make flexible, goal-directed decision in an ever-changing dynamic environment (Matzke, Verbruggen, & Logan, 2016; Verbruggen & Logan, 2008). Impairments in the inhibition function in the form of impulsivity have been argued to pave the way for numerous psychopathologies such as attention deficit/hyperactive disorder, obsessive compulsive disorder, pathological gambling and eating disorders (Boehler, Hopf, Stoppel, & Krebs, 2012; Crews & Boettiger, 2010; Ersche et al., 2012; Matzke et al., 2016; Schachar, Tannock, Marriott, & Logan, 1995; Whelan & Garavan, 2013).

Deficits in response inhibition also prevail in clinical populations. For example, a recent study found schizophrenia patients display decreased response inhibition compared to healthy controls (Limongi, Bohaterewicz, Nowicka, Plewka, & Friston, 2018).

It has long been assumed that inhibition processes in cognitive performance declines with age—that older adults, compared to younger adults are poorer at suppressing prepotent responses and ignoring irrelevant information (Hasher & Zacks, 1988). However, a meta-analysis conducted by Rey-Mermet and Gade (2017) revealed that this inhibition deficit hypothesis should be called into question. They selected 176 studies to review, covering a broad range of tasks commonly assumed to measure inhibition processes (i.e., colour Stroop task, colour-word Stroop task, flanker task, Simon task, global task, local task, positive compatibility task, negative compatibility task, *N*-2 repetition task, stop-signal task and the Go/NoGo task). They opted for a Bayesian approach as well as using multilevel modelling to provide clear statistical support for either the presence or absence of this inhibition deficit effect. Of the 11 tasks analysed, only the Go/NoGo and the stop-signal task revealed an age-related deficit in inhibition.

The stop-signal paradigm allows researchers to quantify inhibitory ability by measuring ones stop signal reaction time (SSRT), the time it takes to halt an initiated response contingent on a stop signal (Eagle et al., 2018). Proposed in 1984 by Logan and Cowen, the independent horse-race model allows researchers to estimate SSRT, which is a latent quantity (i.e., not directly observable). The model proposes a race between two individual runners—the go runner who is triggered by the presentation of go stimulus and the stop runner who is triggered by the stop signal (depicted in Figure 1). If the stop runner finishes the race first the response is successfully inhibited, whereas if the go runner finishes first the response is incorrectly completed (Logan, Zandt, Verbruggen, & Wagenmakers, 2014). Signal-respond trials refer to trials in a stop-signal paradigm where inhibition is required (i.e., there is presentation of a stop-signal) but the go runner escapes inhibition and the response is produced (for a comprehensive review, see van Boxtel, van der Molen, Jennings, & Brunia, 2001). The majority of published stop-signal studies utilized choice response as the primary go task. For example, participants are presented with a left or right oriented arrow and asked to press the corresponding key as fast and accurately as possible except on infrequent occasions when a stop signal is presented after the arrow (Leunissen, Zandbelt, Potocanac, Swinnen, & Coxon, 2017). The independent horse-race model accounts for all variability of response inhibition through the interplay between the stop signal delay (SSD), which is the time difference between the onset of go and the stop signal, and the SSRT (see Figure 1a for visual representation). The model stipulates that the SSD affects the stop-runner; at short SSDs the stop runner is likely to win, but as the SSD increases the stop runner is triggered later and later until eventually the go-runner will always win (i.e., the participant is never able to inhibit the response; Figure 1b). Accurate measurement of SSRT requires that the SSD be manipulated so that participants sometimes fail to stop and sometimes succeed (Matzke et al., 2016). The stop signal paradigm has been used to explore the neural and cognitive mechanisms behind response inhibition and their development across the lifespan. Stopping performance has also been shown to correlate with behaviours such as substance abuse, risk taking and impulse control (Ersche et al., 2012; Schachar et al., 1995; Whelan & Garavan, 2013) consistent with the aforementioned discussion of psychopathologies which arise from impairments in response inhibition.

Although the CR stop-signal paradigm allows for estimation of the speed of the inhibition process, several researchers have noted potential biases in SSRT estimates caused by skewed distribution of response times and response slowing in anticipation of stop-signals (Leunissen et al., 2017; Matzke et al., 2016). Anticipatory response (AR) tasks require go responses to be produced at a fixed time after the beginning of a trial. For shorter intervals, AR response times (RT) is less variable and skewed than choice RT in the simple go tasks used in the stop-signal paradigm. Hence, Leunissen et al. (2017) propose it is better to use AR as the go task when measuring SSRT, that is, an anticipatory response inhibition (ARI) task. An AR task also minimizes the problem of purposeful response slowing to beat the stop signal. Slowing is a viable strategy in choice tasks because it improves accuracy, but in AR it must cause a decrease in accuracy (i.e., responses later than the target time), so as long as participants are required to be accurate it cannot be used to improve stopping.

Furthermore, ARI tasks also allow for the estimation of anticipatory abilities. In the AR trials (without the presentation of a stop-signal), participants are required to anticipate a moving bar and stop the bar as accurately as possible at a fixed marker. A combination of bias scores, which is the difference between their average RT and the fixed marker, and precision scores, which is the standard deviation of their RT allow researchers to quantify the accuracy and consistency of their anticipatory ability (See figure 2 for a visual representation of an example ARI task). The current study incorporates a novel, gamified variant of Slater-Hammel's (1960) AR task to measure AR and to ensure the SSRT estimates are robust and unbiased. The task incorporated game-like elements to 1) reduce fatigue and boredom issues that may arise with the traditional anticipatory tasks (Coxon, Stinear, & Byblow,

2006) and to potentially increase motivation to perform optimally (Boehler et al., 2012), although, Hawkins and colleagues (2013) argue that this may not be the case and 2) to improve face-validity in the gaming context.

The Pathological Framework for Videogaming

There are two distinct approaches in the literature that have examined response inhibition in the context of videogaming—I will describe these approaches as the pathological framework and the adaptive framework.

The pathological framework draws from the traditional use of the term ‘addiction’—which is clinically associated with substance abuse disorders. The framework is part of a growing body of literature that postulates the underlying mechanisms of addiction are not strictly limited to the neurological components of drug use. Rather, it suggests that there are pervasive behavioural factors that see addiction manifest in gambling, sex, pair bonding, work, exercise, use of social media, eating disorders and videogame play (Bari & Robbins, 2013; Blum et al., 2000; Crews & Boettiger, 2010; Griffiths, 1996; Griffiths, 1997).

To delineate addictive behaviour, Griffith (2005) outlined the six core components that need to be fulfilled if a behaviour is to be defined as “addictive”: 1. Salience, which refers to the behaviour becoming the most important activity in one’s life, dominating their thinking, feelings and behaviour; 2. Mood modification, which are the subjective experiences that people report as a consequence of engagement in the behaviour, usually involving feelings of arousal, tranquilizing escape or ‘highs’; 3. Tolerance, which refers to the neurological transformation whereby increasing amounts of the behaviour are needed to achieve the former effects; 4. Withdrawal, which refers to the unpleasant feelings and physical states that occur when the behaviour is discontinued or suddenly reduced; 5. Conflict, referring to both conflicts between the addict and those around them (interpersonal) and within themselves (intrapersonal) where the addict disregards the long-term adverse consequences for short term pleasure; and 6. Relapse, which refers to the tendency to revert to earlier patterns of behaviour which can lead to the most extreme patterns of behaviour (typically seen at the height of addiction) unravelling years of abstinence. Having these six core components as a point of comparison allows researchers to operationally differentiate between what constitutes addictive behaviour and what constitutes excessive behaviour (Charlton & Danforth, 2007).

A host of literature classifies excessive videogaming as an addictive behaviour as it fulfils these criteria, i.e., they manifest the core components of addiction (Charlton & Danforth, 2007; Gentile, 2009; Griffiths, 1997; Griffiths & Meredith, 2008; Grusser, Thalemann, & Griffiths, 2007; Hussain & Griffiths, 2009; Lemmens, Valkenburg, & Peter, 2009; Littel et al., 2012; Weinstein, 2010). (cite, Griffiths, 2005 too). The consensus, within this framework, is that despite the negative physical, psychological and social consequences of excessive videogame play, there is still an engagement in the behaviour—which is grounds for the addiction classification. Furthermore, a reputable organisation has substantiated this evidence by developing clinical criteria for the classification of gaming disorder without needing to substitute "gaming" for "gambling" or "substance use" in existing diagnostics manuals. The World Health Organisation (WHO, 2018) lists excessive gaming as a pathological disorder in the 11th Revision of the International Classification of Diseases (ICD-11). They characterize gaming disorder as having impaired control of the behaviour—allowing gaming to take precedence over other activities and interests. For diagnoses, there must be sufficient severity to result in impairments to personal, family, social, educational or occupational functioning, and despite this, there is still continuation and escalation of the behaviour.

The development of such pathological behaviour stems from the role of reinforcement and reward sensitivity (Blum et al., 2000). Most modern Multiplayer Online Role-Playing Games (MMORPG) and Multiplayer Online Battle Arena (MOBA) games (see titles such as World of Warcraft, RuneScape, League of Legends and StarCraft) have no definitive end point, which introduces the 'grinding' mechanism. Grinding refers to a process where the player completes repetitive, and often tedious, tasks to achieve an award. The reward outcome from grinding is usually contingent on the amount of time invested in the process, e.g., levelling up your character in RuneScape is substantially more time consuming in the later levels compared to the earlier levels as there are diminishing returns for the experience per hour rate. It is argued that the process of grinding is so pervasive and addictive due to these variable-ration, fixed-interval reinforcement schedules. As there are always better rewards to obtain, players tend to respond more rapidly with fewer post-reinforcement pauses (King & Delfabbro, 2009; King, Delfabbro, & Griffiths, 2010).

Littel and colleagues (2012) investigated response inhibition between videogame players (VGP) and non-videogame players (NVGP) by utilizing a Go/NoGo task, where participants were presented with single letters and were asked to respond as quickly as possible to each letter and to withhold their response if the letter was repeated. Only 11% of trials required response inhibition, which is quite rare—and so makes it likely participants will fail to withhold a response. They found that excessive gamers displayed less response inhibition compared to controls. However, of all the NoGo trials, about half were signal-respond trials (i.e., responding when inhibition is required) across all participants—although VGP had significantly more signal-respond trials (54%) compared to NVGP (41%) which can be explained by King and Delfabbro's (2009) findings outlined above. Although the NoGo trials are inherently meant to be difficult, response inhibition could have potentially been better across both cohorts but was mitigated by fatigue (which is likely to occur inside 636 trials), attentional lapses or (lack of) motivation (Padmala & Pessoa, 2010). Furthermore, there was a strong inverse correlation between false-alarms (responding when required to withhold) and reaction time to Go trials, which indicates that as participants responded faster they were less likely to correctly inhibit responses. VGP displayed faster Go reaction times and more false alarms. Because the measure of inhibition in the Go/NoGo task is evidently confounded by speed, it would be more appropriate to employ a stop-signal procedure as the model takes reaction time to go trials into account (Matzke et al., 2016).

It is well established that there are neurological underpinnings to addiction—in substance abuse disorders, there is altered brain activity in areas associated with reward pathways, memory, motivation and cognitive control (Volkow, Fowler, & Wang, 2003). Similarly, research has found that these changes also occur in pathological gamblers (Grant, Brewer, & Potenza, 2006) and in those addicted to internet use and videogames (Kuss & Griffiths, 2012). Furthermore, Ko and colleagues (2009) found increased activation of the right orbitofrontal cortex, bilateral anterior cingulate, medial frontal cortex, right dorsolateral prefrontal cortex, right nucleus accumbens and right caudate nucleus. This indicates a neural pattern of cue-induced cravings—similar to that seen in substance abuse disorders. The evidence for these neurological alterations neatly ties in the notion that excessive videogaming should be considered an 'addiction' to likes of substance abuse and gambling; substantiating the pathological framework.

There is large body of evidence that suggest the impulsive underpinnings are particularly pertinent in the development and maintenance of addictive behaviour (Bechara, Noel, & Crone, 2006; Blum et al., 2000). Of two people who have equal ability, the one who is more impulsive is likely to less take time deliberating before taking action than the other (Dickman, 1990). Researchers have demonstrated that the association between impulsivity and cognitive functioning is not necessarily negative. For example, Dickman and Meyer (1988) showed that those high in impulsivity are more accurate than their low impulsivity counterparts in making decisions when the time to do so is extremely brief. Furthermore, there is less error in the rapid responding of high impulsives when the task is simple (Dickman, 1985). Because there is this discrepancy, Dickman (1990) proposed that there are two separate traits of impulsivity. Functional impulsivity refers to rapid, inaccurate performance in situations when this is optimal. Contrarily, dysfunctional impulsivity refers to rapid, inaccurate performance in situations when this is nonoptimal. Acting on impulses can be inhibited provided there is a reasonable ability and motivation to do so (Fazio & Olsen, 2003). However, it is argued that maintenance of addictive behaviour through continuous engagement in impulsive behaviour significantly impairs inhibitory ability (Bechara et al., 2006).

Working under the assumption that this theoretical framework is true it was hypothesized that as videogame experience increased, anticipatory response inhibition ability would decline. Operationally, I hypothesized a positive correlation between videogame experience and SSRT scores. That is, the time it takes participants to withhold a response contingent on the stop signal would increase as videogaming experience increased. Represented in Figure 2, mediation refers to an intermediary process that the relationship between an independent variable and a dependent variable is contingent on (Muller, Judd, & Yzerbyt, 2005)—and consistent with the pathological framework, it was hypothesized that impulsivity would mediate the relationship between response inhibition and videogame experience. Specifically, I expected scores on either functional or dysfunctional impulsivity to either partially or fully mediate the relationship between videogame experience and SSRT.

The Adaptive Framework for Videogaming

On the contrary, the adaptive framework stems from research into videogaming that has found it improves attention and perception (Clark, Fleck, & Mitroff, 2011), cognitive control, memory and general processing speeds (Dobrowolski, Hanusz, Sobczyk, Skorko, & Wiatrow, 2015) and efficacies in updating task-relevant information (Colzato, van den Wildenberg, Zmigrod, & Hommel, 2013). If specific skills learnt in video games are transferrable to other attentional, perceptual and cognitive tasks then perhaps skills in anticipating and inhibiting responses learnt and practiced in games will manifest in AR and ARI tasks. Games like the Dark Souls series (2011-current) incorporate both AR and ARI mechanisms in having to dodge timed-choreographed attacks or having to inhibit the dodge mechanic when certain attack animations change mid-cast. Most first-person shooter games like the Call of Duty series (2003-current) have an AR and ARI component in having to pre-emptively shoot at moving targets or to cease fire in hostage situations. Even retro games like Mario (1981) require some basic AR in the jumping mechanisms.

A study by Colzato and colleagues (2013) used *N*-back tasks (1-back and 2-back)- where participants are shown a sequence of single letters and are instructed to respond to targets if they matched the letter presented one trial prior in the 1-back condition, or the letter presented two trials prior in the 2-back condition and a choice response stop-signal tasks to investigate the differences in working memory and response inhibition between VGP and NVGP. They found that VGP responded significantly faster to the Go signals but VGP did not differ from NVGP in their SSRT and Go trial error. This comparable response inhibition is contrary to the findings of Littel and colleagues (2012), outlined in the pathological framework, possibly because its measure of response inhibition is confounded by go speed. Therefore, it is possible that by utilizing a measurement of response inhibition that is not similarly confounded, such as an ARI task, statistical differences may arise. Results from the *N*-back tasks revealed that VGP outperformed NVGP in speed and accuracy suggesting improved working memory skills. The observation that playing videogames predicts performance on working memory tasks supports existing literature that videogame experience is linked with improvements of monitoring and updating task-relevant information (Colzato et al., 2013). The underlying mechanisms of videogame play are still disputed (Holst, Brink, Veltman, & Goudriaan, 2010), and the results of this study could suggest that either those with improved working memory capacities are more likely to play videogames, or that playing videogames improves working memory capacity. These findings are contrary to what the pathological framework proposes in regards to the underlying mechanisms—perhaps those who possess more adaptive skills such as improved memory, attention and response inhibition are more likely to be drawn to games and continue to engage in the behaviour as they are more often rewarded. Furthermore, several researchers argue that there is a strong connection between working memory and inhibition (Engle & Kane, 2004).

Thorell and colleagues (2009) sought to extend on this notion that cognitive functions can be improved through training in a novel attempt to investigate if this improvement also pertains to inhibition processes as well as working memory in preschool children. Prior to their study, no research has shown that inhibitory processes can be trained. They argue that working memory and inhibitory control are two of the most fundamental functions of executive control—should they find that these functions can be trained it would have profound implications in the developmental psychology sphere. For example, Klinberg and colleagues (2005) have shown that children with ADHD can improve their working memory, inhibitory control and reasoning ability by training their working memory for 25-40 minutes/day over the course of 5 weeks. In regards to working memory, they had similar findings to Colzato and colleagues (2013). They found that preschool children demonstrated improved working memory abilities after receiving 5 weeks worth of visuo-spatial computerized training. Inhibition was trained with the Go/NoGo task, a stop-signal task (CR go stimulus) and a flanker task, where five arrows pointing either left or right were presented in a row and the goal was to make a response according to the direction of the arrow in the middle while ignoring the arrows on either side (e.g., pressing the right button if the middle arrow is pointing right). Response inhibition was measured by the number of commission errors (i.e., responding when withholding a response is required) on the Go/NoGo task. Following the intervention program, there was no difference in the children's inhibition performance compared to the control group that received no training. Although this does not necessarily validate the adaptive framework, the notion that inhibition can be learned and improved should not be disregarded on the basis of this study alone. Assessing this executive functioning in preschool children raises a caveat in that their prefrontal cortex may not yet be developed enough to sufficiently show training effects. The plasticity in the areas associated with inhibition have been shown to differ from the areas associated with working memory due to the differences in receptor densities (Kuboshima-Amemori & Sawaguchi, 2007). Furthermore, the actual mechanisms of inhibiting a prepotent response is a short neural process—occurring over a few hundred milliseconds. This, in combination with the nature of stop-signal and Go/NoGo tasks (i.e., how inhibition is only required on a minority of trials), means the children only trained their inhibitory abilities a fraction of the time spent training their working memory. So, it seems desirable that the learning and training of inhibition be examined in a cohort where a) the participants have reached developmental maturity and have fully developed executive functions and b) the 'intervention' or 'training program' is robust, intensive and over a longer period of time (e.g., videogaming). This way, we may expect to see improvements similar to the other cognitive functions previously outlined.

Should this framework be the dominant model to fit the videogame experience-inhibition dyad, it is expected that those who play more videogames are more likely to have learned and honed (through repetition and practice) their AR and ARI skills. Consequently, it was hypothesized that as videogame experience increased, anticipatory response inhibition ability would improve. I operationalized this by hypothesizing that as videogame experience increased, SSRT would decrease. I also expected to see this negative correlation manifest between videogame experience and bias and precision scores, i.e., as videogame experience increases, bias and precision scores would decrease. Bias and precision scores refer to the participants' ability to respond consistently accurate—I expand on the operational definitions later, in the analysis section.

Method

Design

I used a correlational design for two main reasons. The first is to avoid throwing away data points by discretising the data and using summary statistics, i.e., t-tests or analyses of variance (ANOVA). The second is that the literature that measured videogaming experience did not provide justification for the cut-off of being either a videogame player (VGP) or a non-videogame player (NVGP) (Clark et al., 2011; Colzato et al., 2013; Littel et al., 2012; Mcdermott, Bavelier, & Green, 2014). To dichotomize my data points into either VGP or NVBGP would have required me to create an arbitrary cut-off. This is inconsistent and unjustified in the existing literature; for example, Clark and colleagues (2011) required participants to have played at least 6 hours of games in the last 6 months to qualify as a VGP whereas Colzato and colleagues (2013) only required 5 hours but excluded participants who have played role playing games (which appears counterintuitive as role playing games contain their dependent variables of working memory and inhibition). On the other hand, Little and colleagues (2012) did not care about hours played and only screened for players who played World of Warcraft (without providing justification as to why). This design consisted of bias, precision and SSRT scores being regressed on videogame experience. As part of the mediation component of the analysis, SSRT scores and videogame experience was regressed on both functional and dysfunctional impulsivity

Participants

Thirty nine, adult participants aged 19-69 (M=28.80, SD=13.80, 13 females, see Appendix A for full demographic information) were recruited from a pool of first year undergraduate Psychology students from the University of Tasmania (UTAS) as well as from the general population. The sample size was contingent on recruiting up until the second week of August to remain within the thesis timeframe. Participants from the general population were primarily recruited through social media and on campus flyers. The Psychology students were awarded course credit for their participation and the others went in the draw to win one of six $50 JB-Hi-Fi gift vouchers. Prior to testing, participants were given an information sheet detailing the study and then offered an opportunity to ask questions. They then completed a videogame experience questionnaire and a self-report impulsivity inventory. According to Boot, Blakely and Simons (2011), such covert recruitment strategy is ideal to avoid the possibility that expectations and motivation drive VGPs/NVGPs differences in cognitive tasks. One participant was removed from all analyses as their pattern of results did not fit the assumptions of horse-race model speeding—that is, their go-runner was faster in the presence of a stop-runner than without (Matzke et al., 2016).

Apparatus/materials/instruments

Dickman's (1990) inventory was used to assess levels of self-reported functional and dysfunctional impulsivity, with participants responding True or False to a battery of 23 questions (Appendix D). The videogame questionnaire, adapted from existing literature (Clark et al., 2011; Dobrowolski et al., 2015; Mcdermott et al., 2014) produced a score of the participants' videogame experience (Appendix E). Participants listed, where applicable, up to three of their most frequently played games in the last 12 months. If they had not played any games, they wrote "Nil".

Participants then indicated, on average, how many hours a week they played videogames. They did this for each three-month period dating back 12 months. The experiment was run on a PC, with a graphics card that allowed it to run at 100fps, attached to a 17inch monitor (144 Hz). The program used to test AR and ARI was called ARI's Staff and was run as an executable file (.exe) on the PC. The program was created collaboratively in Unity (2017) by Chris Thongnoppakun, Matthew Gretton and Andrew Heathcote.

Procedure

Participants completed two, back to back, 50-minute sessions. In the first session they were briefed on the experiment then completed the videogame questionnaire and the impulsivity inventory. They then completed 30 minutes' worth (720 trials) of AR trials. In their second session they completed 1200 trials of ARI's Staff with the inclusion of 400 ARI trials (so 800 AR trials). The occurrence and order of the ARI trials were randomized for each participant; therefore, each participant completed a differently ordered version of the task. The task is an adaption from the AR paradigm task from Slater-Hammel's (1960) study, where to estimate anticipatory responding an indicator increases upwards at a constant velocity reaching the top of the scale 1 second after beginning to rise, and participants are instructed to stop the indicator as close to a marker (crossed at 800ms) as possible.

The game, ARI's Staff, is centred around a mage wielding a volatile staff who must escape from the catacombs from which the staff was stolen. The exit is fortified by a runic barrier. The mage's only chance at escaping is to destroy the barrier with magic generated by performing the anticipated response and inhibition tasks (see Appendix for screenshots of the game. As with Slater-Hammel's task the current task involved a charge bar which increases at a constant velocity until a cut-off at 1 second. Participants were asked to stop the charge as close to the 800ms marker as possible by pressing the spacebar key. Damage feedback was calculated by max(0,10000 * (1-(|diff|/scale))), where *diff* is the difference between response time and 800ms and scale is the time difference from 800ms where the damage will equal 0. As *scale* was set to equal 100ms, there was 0 damage feedback for a response, <700ms or >900ms. So, if the participant responded at 840ms, 840ms was subtracted from 800ms resulting in a *diff* score of -40ms. For scoring purposes, it didn't matter if participants responded before or after 800ms so |-40ms| is 40ms. From here 40ms was divided by 100ms (the *scale* value) resulting in 0.4. Provided the participant responded within 700ms and 900ms they would end up with a number <1. The number produced by the aforementioned formula is arbitrary and served only as feedback for participant's motivation levels. Progression through each level was determined by how long it took to bring down the barrier twice. The barrier had 156 hit-points (HP). Responding more than 100ms from the 800ms optimal constituted a weak blast and caused 1 damage to the barrier. Responding between 15ms and 100ms of the optimal constituted a good blast and caused 2 damage to the barrier. Responding less than 15ms from the optimal constituted a powerful blast and caused 4 damage. Failure to respond in less than 1 second, or trigger failure, caused the barrier to regenerate 4HP. The fortified barrier had a finite health bar, represented by a series of runes and each attack diminished them. As more powerful attacks, generated by more accurate anticipatory responding or successful inhibition, produced more damage, the barriers would be destroyed much quicker allowing for more breaks. Called a block break, every time the barrier was fully destroyed the participated was able to rest for 8 seconds while Ari's staff recharged, or they progressed to the next room.

For the ARI trials, the charge bar turned blue to indicate participants to withhold a response. Successful inhibition produced a powerful attack (4HP damage to the barrier) and failure to inhibit incurred regeneration of the barrier (4HP regeneration to the barrier). A staircase procedure adjusted the SSD so that response inhibition was only successful half the time. The initial onset for the stop-signal started at 400ms and increased by 20ms if the participant successful inhibited or decreased by 20ms if they failed to inhibit within the limits of a 40ms minimum and a 760ms maximum. Damage feedback for the ARI trials was calculated with the formula 10 * (200+(SSD * 1000)). So, if the participant successfully inhibited at the starting SSD (0.4s) they would score 6000 points. To further increase motivation, and to address the few participants who queried about progression, participants were encouraged to try their hardest as they were told that the more damage they did the faster they would break down the barrier and get through the room. To encourage participants, they were told that due to the volatility of the (stolen) staff it would be very hard to use it to its full potential and they will probably fail the inhibition about half the time.

Analysis

AR bias scores, where smaller values indicated better performance, were derived from the difference between reaction time and 800ms, and AR precision scores were derived from the standard deviation of RT. SSRT were calculated with both the mean method, where the SSD is subtracted from the go RT, and the integration method, where the go RT distribution is integrated to find the point where the integral equals the probability of responding, then subtracting the SSD from this (Leunissen et al., 2017; Verbruggen, Chambers, & Logan, 2013). Several regression analyses were run to examine the relationship between videogame experience and AR and ARI. Bias, precision, mean SSRT and integrated SSRT scores were regressed on gaming experience. Separate regression analyses were conducted to investigate whether functional and dysfunctional impulsivity were mediators for the gaming experience-ARI relationship; i.e., both mean and integrated measurements of SSRT were regressed on FI and DI and FI and DI were regressed on gaming experience. I also conducted Bayes Factor (BF) analyses for the associations delineated above. I used the default setting for the prior in the BF analyses (r=1/3).

Results

Videogaming experience was coded through a series of functions that transformed the data on the gaming questionnaire into an arbitrary whole number—the bigger the number inferring higher videogaming experience. First, an expert panel of three coded each individual game based on whether the game had no, low, or high levels of AR and ARI components. All games had gameplay footage reviewed on YouTube to assess these components. A game with no AR or ARI was given the coefficient 0, a game with low AR or ARI was given the coefficient 1, a game with high AR or ARI was given the coefficient 2. For example, League of Legends is a fast paced multiplayer online battle arena game and has both high AR and ARI, giving it a score of 4 (derived from an AR score of 2 and an ARI score of 2). For a complete list of the game scores, refer to Appendix B. The game score for each individual game was added up for all the games indicated by the participant. Second, the average hours per week was added up for each 3 month interval (i.e., the average hours for the 0-3month interval was added to the 3-6month interval, and so on) and then multiplied by 13 (as there are 13 weeks in 3 months). This gave a figure of the average amount of time spent playing videogame over the course of 12 months. Last, the total hours over the 12 month period was multiplied by the total game score (up to 3 games), producing a figure which gets larger based on more gaming hours invested and games high in AR and ARI components.

As outlined earlier, there is an age-related inhibition deficit present in stop-signal tasks (Rey-mermet & Gade, 2017). Older adults, particularly those over 40 also predominantly had no videogame experience whatsoever (see Figure 8). A combination of these factors made me tentative in running the analyses as there was potential to confound the results. Participants who were over 40 were removed for the purpose of running a conservative analysis not biased by known confounds. The following analyses were also run with the inclusion of the older adults and can be viewed in Appendix G.

On the stop trials, all participants correctly withheld their responses around 50% (no participant stopped under 50% and the highest probability of stopping was 51.5%)—a rate which is desirable for the reliable estimation of SSRT with the mean and integrated method per variable SSDs (Band, van der Molen, & Logan, 2003). Videoaming experience negatively correlated with both integrated SSRT $r(30)=-0.38$, $p=.033$, BF=2.71 (Figure 4), and mean SSRT, $r(30)=-0.32$, $p=.015$, BF=4.77 (Figure 5). The data increased the belief that an association exists between videogaming experience and mean SSRT and integrated SSRT by a factor of 4.8 and 2.7, respectively. There was also a significant association between videogaming experience and overall bias scores in the first session, $r(30)=-0.35$, $p=.046$, BF=2.12, but not the second, $r(30)=-0.06$, $p=.737$, BF=0.41. In the first session, the data increased the belief that an association exists between videogaming experience and bias by a factor of 2.1, while in the second session, the data increased the belief that no association exists between videogaming experience and bias by a factor of 2.4. Although this initially appeared to indicate that as videogaming experience increased in the first session, bias scores would decrease, examination of Figure 6 reveals that there was no systematic way to interpret the relationship because participants could produce negative bias scores as well as positive ones. As better bias scores would mean scoring closer to 0, the relationship only implies that, in the first session, those with more videogaming experience were more likely to respond, on average, before the 800ms indicator.

There was no overall association between videogaming experience and precision scores in the first session, $r(30)=-0.05$, $p=.772$, BF=0.40 nor the second, $r(30)=0.12$, $p=.500$, BF=0.47. The data increased the belief that no association exists between videogaming experience and precision scores in sessions 1 and 2 by a factor of 2.5 and 2.1, respectively. However, to investigate if there was a component of learning (i.e., initially an association existed but after practice, all participants improved and the associated disappeared), I grouped all precision scores into 6 blocks, which consisted of pairing each block break to get a reasonable number of blocks. I then ran separate regression analyses for the videogaming experience-precision dyad in each block as a follow up. There was a significant negative correlation between videogaming experience and precision in block 1, $r(30)=-0.42$, $p=.017$. Illustrated in Figure 8, this association means that as videogaming experience increases, participants become more precise in their responding, i.e., the SD of their RT reduces. This negative correlation dissipated in blocks 2, $r(30)=-0.22$, $p=.222$, 3, $r(30)=-0.02$, $p=.902$, 4, $r(30)=0.21$, $p=.238$, 5, $r(30)=-0.31$, $p=.081$, and 6, *r*(30)=0.12, *p*=.503, indicating that there was a learning effect for the precision of responses whereby those with less videogame experience rapidly caught up to those with more experience.

To investigate the possible mediation of impulsivity on the videogaming experience-SSRT relationship, several regression analyses were conducted. There was a positive correlation between functional impulsivity and integrated SSRT, *r*(30)=0.40, *p*=.023, BF= but not with mean SSRT, *r*(30)=0.31, *p*=.084. Dysfunctional impulsivity positively correlated with both mean SSRT, *r*(30)=0.38, *p*=.034, and integrated SSRT (30)*r*=0.38, *p*=.031. However, the Pearson's product-moment correlation analyses revealed no significant association between videogaming experience and functional, *r*(30)=-0.27, *p*=.142, or dysfunctional, *r*(30)=0.03, *p*=.863, impulsivity. As there was no significant relationship between the possible mediators (functional and dysfunctional impulsivity) and the predictor variable, there was not enough justification to perform a mediational analysis, as illustrated in Figure 3. That is, for there to be mediation there must 1) be a significant overall treatment effect where the independent variable affects the outcome variable (in this case, there was), 2) variability in the mediator can be explained by variability in the independent variable (in this case, this condition was not met), 3) variability in the outcome variable can be explained by variability in the mediator, while controlling for the predictor, and 4) the effect of the independent variable on the outcome variable should be smaller in the third regression compared to the first (Baron & Kenny, 1986).

Discussion

This study investigated anticipatory response and inhibition ability in relation to videogame experience. I wanted to explore whether anticipatory response and inhibition would improve with videogame experience as a result of learning and training the relevant cognitive functions, per the adaptive framework; or if the pathological framework was true and anticipatory response inhibition would decline with videogame experience because of the underlying components of reduced inhibition, reward sensitivity and increased impulsivity, similar to other behavioural addictions.

Anticipatory response inhibition in videogamers

The results predominantly provide evidence for the adaptive framework. The hypothesis pertaining to the relationship between videogame experience and inhibition was supported; i.e., as videogame experience increased, anticipatory response inhibition ability would improve. This was evident from the significant negative correlation between videogame experience and SSRT (calculated with both mean and the integrated method). This implies that as videogame experience increases, their SSRT decreases, indicating a faster inhibitory process. There has been some literature that argues the efficacy of the mean method compared to the integrated method in the reliable estimation of SSRT per fixed SSD (Logan, Schachar, & Tannock 1997). With variable SSDs, as with this study, as long as the probability of stopping is close to 50%, both the mean and integrated method are reliable estimates of SSRT (Band, van der Molen, & Logan, 2003). As the probability of stopping was very close to exactly 50% across all participants, and both the mean and integrated method significantly correlated with videogame experience, these findings can be examined with the confidence that the estimations of SSRT are reliable and are not confounded by measurement methodology. The data were analysed with a conservative approach in that I considered the possibility that age would confound inhibitory performance. Participants aged over 40 were also clear outliers when it came to videogame experience (i.e., they had little to no experience, whereas participants under 30 displayed a large range of experience). Because of these two possible confounds, I removed those aged over 40 from the analyses. Although this may have reduced the power of the analyses and made the data less generalizable, it was necessary to ensure the relationship between videogame experience and inhibitory ability was examined without the influence of known confounds.

Anticipatory responding ability in videogamers

The ability to anticipate a response and execute it accurately and consistently is not discussed in the pathological framework, and is referred to in the context of motor functioning, general reaction times and processing speeds in the adaptive framework (Colzato et al., 2013; Dobrowolski et al., 2015; Rosenberg, Landsittel, & Averch, 2005). This is likely due to inhibition not yet being assessed in ARI stop-signal tasks. Although the measures of bias, which is the difference between their average RT and the fixed marker, and precision, which is the standard deviation of their RT, was only a by-product of the ARI task, the results yielded some interesting findings. The significant negative correlation between overall bias scores and videogame experience, albeit not systematically interpretable with this design, could possibly provide useful information if analysed a different way. If the distribution of scores never crossed 0 and a significant negative relationship was found, it would show that as videogame experience increases, the difference between a perfect response and average RT would decrease. This would imply that as people had more gaming experience, their anticipatory response ability was more accurate. If the line of best fit did cross 0, as with this study, perhaps the bias scores could be analysed as absolute values (i.e., whether or not the value is positive or negative is irrelevant). As smaller (closer to 0) scores mean better bias, absolute values in a correlational design would be interpretable. There is, however, a plausible explanation for the pattern of results found in this study—that is, participants with more videogame experience were more likely to respond before the fixed marker and those with less experience were more likely to respond after. Many fighting games and role-playing games (see titles such as Dragon Ball Z Budokai Tenkaichi, Dark Souls, Skyrim and Uncharted) heavily penalize late responses, usually resulting in failure of a given task or death of a character, whereas premature responses generally are not penalized as harshly. For example, charging an attack in Dragon Ball Z Budokai Tenkaichi involves a hold-and-release process; if the attack is held for too long past the final indicator, the player is left stunned and open for attack, whereas if the player releases the key prematurely the attack is simply weaker than an optimally charged attack. If the learning and training process outlined in the adaptive framework is true, this pattern of responding should also manifest in the ARI task. A preferred pattern of results to support the adaptive framework would be one that yields a negative correlation between videogame experience and bias scores that does not cross 0. However, the pattern of results found in this study technically maps on quite well to the adaptive framework—gamers, due to mechanisms of reinforcement (King, Delfabbro, & Griffiths, 2010) and punishment, learn to time their responses slightly before the optimal so as to maximize their chances of reward while minimizing the risk of missing the response entirely.

The results did not show a significant relationship with overall precision scores and videogame experience. To support the adaptive framework, the desirable result would be a significant negative correlation which would imply that as videogame experience increased, precision scores decreased—meaning participants with more gaming experience were more consistent in their responding. Following the partitioning of precision scores into six separate blocks yielded this pattern of results in the first block. The first block consisted of the average of all the standard deviations of RT for the first two block breaks (each block contained roughly 4 minutes worth of trials). So, at least for the first 8 minutes of testing, those with more videogaming experience were responding more consistently precise compared to those with less videogaming experience. In the first session alone, there was 720 trials of anticipatory responding. Furthermore, compared to a complex executive function such as inhibition, timing one's responses to a bar that does not change speed and provides feedback is relatively trivial and easy. The learning of being consistently precise inadvertently provides evidence for the adaptive framework. In this case, ARI's staff was the "intervention/training program" (Thorell et al., 2009) where the cognitive function of responding consistently precise was trained. Prior to this training, those with more gaming experience performed better likely due to having learned and practiced this mechanism in videogaming. For example, in video games such as Guitar Hero, where for better scores, it is required that the player consistently hits the correct key at the correct time. As the player progresses through the game they are required to press more keys at shorter intervals making the game harder and the "training" progressive. Another example is the "farming" mechanic, where the player has to click on minions at a particular threshold of health in order to gain and maintain income, in MOBA games such as League of Legends. In a single game, a player is required to accurately anticipate and execute a response over 500 times.

Impulsivity in videogamers

The results pertaining to the pathological framework hypothesis that due to impulsive underpinnings, excessive videogamers are likely to have impaired anticipatory response inhibition were inconclusive. Overall, there were not enough significant relationships to satisfy the requirements to perform a mediational analysis (Baron & Kenny, 1986). Dysfunctional impulsivity positively correlated with both mean and integrated SSRT, implying that those higher in dysfunctional impulsivity were more likely to have slower SSRT—consistent with the pathological framework. This relationship indicates that those who make quick decision without deliberation in situations where it is non-optimal to do so (Dickman, 1990) are more likely to have poorer inhibitory functioning. Functional impulsivity, which refers to quick decision making in situations where it is optimal to do so, positively correlated with integrated SSRT but not with mean SSRT. This inconsistency is likely due to the relationship bordering the frequentist's statistical significance but not quite reaching the threshold of p=.05 because of differences in measurement methodology of SSRT estimates (Leunissen et al., 2017). However, even if mean SSRT significantly correlated with functional impulsivity, neither functional nor dysfunctional impulsivity correlated with videogame experience—failing to meet to the "a" pathway criterion outlined in Figure 3.

Although there were insufficient correlations to perform a mediational analysis, the notion that impulsivity mediates the videogame experience-inhibition relationship should not be entirely discarded. As the literature stipulates, impulsivity underlies those with behavioural *addictions* (Bechara, Noel, & Crone, 2006; Blum et al., 2000). Perhaps, through biased recruitment methods, participants did not manifest any of the addiction components in relation to videogaming as they were only excessive gamers—a distinction that is necessary to make (Charlton &

Danforth, 2007). In hindsight this is relatively easy to address, and recommendations are made later on. With this in mind, the pathological framework could still well be true, and that impulsivity would mediate inhibitory performance in addictive videogamers rather than excessive videogamers.

Implications

In regard to real-world application of these findings, I believe the most important implication, which is not so obvious, is that pathological gaming should not be defined on the basis of hours invested in the behaviour alone. This study has shown that those who have engaged over 40 hours of videogame play a week, which is well over the threshold defined by the WHO (2018), still may not have impulsive underpinnings or manifest any of the components of addiction. Furthermore, those who spend a lot of time playing videogames appear to have learned and improved their cognitive functioning—demonstrating superior inhibitory ability and anticipatory response precision compared to their counterparts who spend less time gaming. As a result of the findings of this study, it should be emphasized that there must be a distinction between pathological gamers and excessive gamers—and that the latter may be more adaptive than detrimental.

As precision scores demonstrably improved across all participants with the progression of ARI's staff, it could be argued that the task itself could serve as a cognitive training apparatus.

Limitations

Thorell and colleagues (2009) acknowledge a glaring limitation of studies that investigate cognitive training: There is inconsistency regarding the types of effects that can be demonstrated in different training programs. First, there are likely to be practice effects on the tasks themselves. Second, there could be training effects on non-trained tasks that measure the particular cognitive aspect targeted by the training program. Last, there could be transfer or generalizable effects to related constructs (i.e., working memory training having an effect on inhibition functions). So, if ARI's staff is to be considered a training program, it is cautioned that these confounding effects be considered.

Another limitation is that I only looked at global inhibition in the current study. This could potentially confound the estimates of SSRT as it has been shown that global inhibition is a substantially easier task compared to selective inhibition (Coxon et al., 2007).

It is common practice in psychological research to improve data quality by adding gamelike features to experiments to improve attention and motivation. Hawkins and colleagues (2013) demonstrated this is not necessarily accurate. They empirically tested the effect of gamelike features of task performance, which had not yet been done, and found that there was no difference in response latency, decision accuracy and points scored in statistically identical tasks, where one had gamelike features and one did not. Their gamelike features included a story and objective, pixel rendering, colouration and the inclusion of progressive difficulty. A demo version of their "game" was accessible online. The game ran at under 20fps (which has substantially more lag than most modern games that run at least 60fps). Compared to ARI's staff which was professionally developed on a triple A game engine and ran at well over 60fps, their game's gamelike features appeared quite subpar. With ARI's staff, participants, particularly the first year undergraduate students who had undertaken several other psychological tasks, informally reported the game was enjoyable and they were motivated to try and progress through the dungeon and /or beat their peers. The feedback provided in ARI's staff was multifaceted and participants were motivated to perform optimally and punished for performing poorly. It is well established that tasks that are motivating and detract participants from the monotony of completing many trials yield less variable and better data (Weinbach, Kalanthroff, Avnit, & Henik, 2015). Because of how well ARI's staff was developed, the limitations proposed by Hawkins and colleagues (2013) should only be tentatively applied, if at all, to the current study.

Recommendations for future studies

Although a significant relationship in this videogaming-inhibition dyad was revealed, despite a small sample size, causality cannot be directly inferred as there was no experimental manipulation of the predictor. That is, because participants were randomly recruited there could be a number of factors that contribute to the variance in their inhibitory ability. Ideally, to investigate if playing videogames can improve inhibitory ability through training, I recommend that, as well as recruiting a larger sample of people under 30, participants be randomly allocated into either a training group or a control group. The training cohort would spend some time playing the games high in anticipatory inhibition components (see Appendix B for a comprehensive list of popular games and their anticipatory response and inhibition scores), while the control cohort would play puzzle or board games (i.e., games with no AR or ARI). After the training period, which ideally should be quite lengthy as the neural mechanisms of inhibition are short and require more training compared to other executive functions (Thorell et al., 2009), both cohorts will then complete ARI's Staff, as with this study. Instead of a regression analysis being performed, an ANOVA will examine if there are any differences in SSRTs between the two groups. If there is statistical significance in the difference between the two groups on their SSRT scores causal inferences can be made for the role of videogaming on response inhibition. The learning and improvement of response inhibition following videogaming under controlled conditions would provide strong evidence for the adaptive framework.

Without utilizing a design where there is experimental manipulation , there is still a way to be more concise in the differentiation between addictive behaviour and excessive behaviour. The measurement of videogaming in this study was relatively robust to those seen in previous studies (Clark et al., 2011; Dobrowolski et al., 2015; Mcdermott et al., 2014) as it measured the averaged time spent playing games over the course of a year broken down weekly for each three month interval, taking into consideration the type of game played. Still, this comprehensive measure does not capture the underpinnings outlined in the pathological framework. Therefore, it is recommended that measurements of the six components of addiction be collected (i.e., salience, mood modification, tolerance, withdrawal, conflict and relapse; Griffiths, 2005) as well as a general measure of videogame experience. These components of addiction can be included in a multivariate analysis to examine if there are any differences in SSRTs between excessive gamers and pathological (those who manifest the six components of addiction as well) gamers. Compared to the previous studies that dichotomized participants into either “videogamers” or “non-videogamers” on a seemingly arbitrary basis (i.e., to qualify as a videogamer, participants had to meet a cut-off criterion for hours played per week), the theoretical justification on classifying a pathological gamer is well defined. For example, the World Health Organisation (2018) has operationally defined pathological gaming to a set of clinical criteria.

A two-process model is proposed to explain how inhibition of non-selected responses and inhibition of selected responses operate in concert (Greenhouse, Sias, Labruna, & Ivry, 2015). Future studies that utilize ARI's staff in examining inhibitory processes may consider differentiating between these two independent processes (i.e., selective versus global suppression of responses) as it has been shown that the neural pathways involved differ (Claffey, Sheldon, Stinear, Verbruggen, & Aron, 2010; J. P. Coxon et al., 2007; James P Coxon et al., 2006). That is, different neural mechanisms that are used when a single action is cancelled in response to new information, while continuing others is different to when there is global suppression (Aron & Verbruggen, 2008). In their 2007 study, Coxon and colleagues examined the selective inhibition of motor output at the behavioural level. They define selective inhibition as the ability to withhold one movement while concurrently executing another. This selective inhibition is thought to compromise speed for specificity and may have a greater generalisability to naturalistic settings where timing of response and cancellation is less restricted (Claffey et al., 2010). Coxon and colleagues (2007) developed a novel adaption of an ARI task where participants were required to stop *two* moving indicators at a fixed point. For their unimanual experiment, each indicator was independently operated by index finger and middle finger of one hand, while in the bimanual experiment the indicator was operated by the index finger of each hand. In the selective inhibition trials, they found inhibition deficits in both the unimanual and bimanual conditions—supporting the notion that selective inhibition is harder to perform than non-selective inhibition due to less direct neural pathways. As it is unclear which direction selective inhibition would influence the videogame experience-inhibition dyad, it is recommended that ARI's staff is modified to include two charge bars for future studies.

References

Band, G. P. H., van der Molen, M. W., & Logan, G. D. (2003). Horse-race model simulations of the stop-signal procedure. *Acta Physiologica*, *112,* 105-142.

Bari, A., & Robbins, T. W. (2013). Progress in Neurobiology Inhibition and impulsivity: Behavioral and neural basis of response control. *Progress in Neurobiology*, *108*, 44–79. https://doi.org/10.1016/j.pneurobio.2013.06.005

Baron, R. M., & Kenny, D. a. (1986). The Moderator-Mediator Variable Distinction in Social Psychological Research: Conceptual, Strategic, and Statistical Considerations. *Journal of Personality and Social Psychology*, *51*(6), 1173–1182. https://doi.org/10.1037/0022-3514.51.6.1173

Bechara, A., Noel, X., & Crone, E. A. (2006). Loss of Willpower: Abnormal neural mechanisms of impulse control and decision making in addiction. In R. W. Wiers & A. W. Stacy (Eds.), *Handbook of implicit cognition and addiction.* Thousand Oaks, CA: SAGE Publications.

Boehler, C. N., Hopf, J. M., Stoppel, C. M., & Krebs, R. M. (2012). Motivating inhibition - reward prospect speeds up response cancellation. *Cognition*, *125*(3), 498–503. https://doi.org/10.1016/j.cognition.2012.07.018

Brown, R. I. F. (1991). Gaming, gambling and other addictive play. In J. H. Kerr & M. J. Apter (Eds.), *Adult place: A reversal theory approach*. Amsterdam: Swets & Zeitlinger.

Brown, R. I. F. (1993). Some contributions of the study of gambling to the study of other addictions. In W. R. Eadington & H. J. Shaffer (Eds.), *Gambling behavior and problem gambling*. Reno, NV: University of Nevada Press.

Charlton, J. P. (2002). A factor-analytic investigation of computer 'addiction' and engagement. *British Journal of Psychology*, *93*(329-344).

Charlton, J. P., & Danforth, I. D. W. (2007). Distinguishing addiction and high engagement in the context of online game playing. *Computers in Human Behavior*, *23*, 1531-1548.

Claffey, M. P., Sheldon, S., Stinear, C. M., Verbruggen, F., & Aron, A. R. (2010). Having a goal to stop action is associated with advance control of specific motor representations. *Neuropsychologia*, *48*(2), 541–548. https://doi.org/10.1016/j.neuropsychologia.2009.10.015

Clark, K., Fleck, M. S., & Mitroff, S. R. (2011). Enhanced change detection performance reveals improved strategy use in avid action video game players. *Acta Psychologica*, *136*(1), 67–72. https://doi.org/https://doi.org/10.1016/j.actpsy.2010.10.003

Colzato, L. S., van den Wildenberg, W. P. M., Zmigrod, S., & Hommel, B. (2013). Action video gaming and cognitive control: Playing first person shooter games is associated with improvement in working memory but not action inhibition. *Psychological Research*, *77*(2), 234–239. https://doi.org/10.1007/s00426-012-0415-2

Coxon, J. P., Stinear, C. M., & Byblow, W. D. (2006). Intracortical Inhibition During Volitional Inhibition of Prepared Action. *Journal of Neurophysiology*, *95*, 3371–3383. https://doi.org/10.1152/jn.01334.2005.

Coxon, J. P., Stinear, C. M., & Byblow, W. D. (2007). Selective Inhibition of Movement. *Journal of Neurophysiology*, *97*(3), 2480–2489. https://doi.org/10.1152/jn.01284.2006

Crews, F. T., & Boettiger, C. A. (2010). Impulsivity, Frontal Lobes and Risk for Addiction Fulton. *Pharmacology Biochemistry and Behavior*, *93*(3), 237–247. https://doi.org/10.1016/j.pbb.2009.04.018.Impulsivity

Dickman, S. J. (1990). Functional and dysfunctional impulsivity: Personality and cognitive correlates. *Journal of Personality and Social Psychology*, *58*(1), 95–102. https://doi.org/10.1037/0022-3514.58.1.95

Dobrowolski, P., Hanusz, K., Sobczyk, B., Skorko, M., & Wiatrow, A. (2015). Cognitive enhancement in video game players: The role of video game genre. *Computers in Human Behavior*, *44*, 59–63. https://doi.org/10.1016/j.chb.2014.11.051

Eagle, D. M., Baunez, C., Hutcheson, D. M., Lehmann, O., Shah, A. P., & Robbins, T. W. (2018). Stop-Signal Reaction-Time Task Performance: Role of Prefrontal Cortex and Subthalamic Nucleus. *Cerebral Cortex*, *18*(January 2008), 178–188. https://doi.org/10.1093/cercor/bhm044

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In Brian H. Ross (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 44, pp. 145–199). New York: Elsevier Science.

Ersche, K. D., Jones, P. S., Williams, G. B., Turton, A. J., Robbins, T. W., & Bullmore, E. T. (2012). Abnormal Brain Structure Implicated in Stimulant Drug Addiction. *Science*, *335*, 601–605.

Fazio, R. H., & Olson, M. A. (2003). Implicit measures in social cognition research: Their meaning and use. *Annual Review of Psychology*, *54*, 297-327

Gentile, D. (2009). Pathological Video-Game Use Among Youth Ages 8 to 18: A National Study. *Psychological Science*, *20*(5), 594-602.

Grant, J. E., Brewer, J. A., & Potenza, M. N. (2006). The neurobiology of substance and behavioral Addictions. *CNS Spectrums*, *11*(12), 924-930.

Greenhouse, I., Sias, A., Labruna, L., & Ivry, R. B. (2015). Nonspecific Inhibition of the Motor System during Response Preparation. *Journal of Neuroscience*, *35*(30), 10675–10684. https://doi.org/10.1523/JNEUROSCI.1436-15.2015

Griffiths, M. D. (1996). Nicotine, tobacco and addiction. *Nature, 384*, 18.

Griffiths, M. D. (1997). Computer Game Playing in Early Adolescence. *Youth Society, 29*, 223-237.

Griffiths, M. D. (2005). A 'components' model of addiction within a biopsychosocial framework. *Journal of Substance Use*, *10*(4), 191 - 197.

Griffiths, M. D., & Meredith, A. (2009). Videogame Addiction and its Treatment. *Journal of Contemporary Psychotherapy*, *39*, 247-253.

Grusser, S. M., Thalemann, R., & Griffiths, M. D. (2007). Excessive Computer Game Playing: Evidence of Addiction and Aggression? *Cyber Psychology & Behavior*, *10*(2), 290-292.

Hasher, L., &Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.). *The psychology of learning and motivation* (Vol. 22, pp. 193–225). San Diego, CA: Academic Press.

Hawkins, G. E., Rae, B., Nesbitt, K. V, & Brown, S. D. (2013). Gamelike features might not improve data. *Behavioural Research*, *45*, 301–318. https://doi.org/10.3758/s13428-012-0264-3

Holst, R. J. Van, Brink, W. Van Den, Veltman, D. J., & Goudriaan, A. E. (2010). Why gamblers fail to win: A review of cognitive and neuroimaging findings in pathological gambling. *Neuroscience and Biobehavioral Reviews*, *34*, 87–107. https://doi.org/10.1016/j.neubiorev.2009.07.007

Hussain, Z., & Griffiths, M. D. (2009). Excessive use of Massively Multi-Player Online Role-Playing Games: A Pilot Study. *International Journal of Mental Health and Addiction, 7,* 563-571.

King, D., & Delfabbro, P. (2009a). Understanding and Assisting Excessive Players of Video Games: A Community Psychology Perspective. *Australian Community Psychologist, 21,* 62-74.

King, D., & Delfabbro, P. (2009b). Motivational differences in problem video game play. *Journal of Cybertherapy and Rehabilitation, 2,* 139-150.

King, D., Delfabbro, P., & Griffiths, M. D. (2010). The Role of Structural Characteristics in Problem Video Game Playing: A Review. *Cyberpsychology, 4*(1), 1-8.

Klingberg, T., Fernell, E., Olesen, P.J., Johnson, M., Gusta fsson, P., Dahlström, K., Gillberg, C.G., Forssberg, H., & Westerberg, H. (2005). Computerized training of working memory in children with ADHD: a randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44,* 177–186.

Ko, C.-H., Liu, G.-C., Hsiao, S., Yen, J.-Y., Yang, M.-J., Lin, W.-C., . . . Chen, C.-S. (2009). Brain activities associated with gaming urge of online gaming addiction. *Journal of Psychiatric Research, 43,* 739-747.

Kuboshima-Amemori, S., & Sawaguchi, T. (2007). Plasticity of the primate prefrontal cortex. *Neuroscientist, 13*, 229–240.

Kuss, D. J., & Griffiths, M. D. (2012). Internet and gaming addiction: A systematic literature review of neuroimaging studies. *Brain Sciences, 2*, 347-374.

Lemmens, J. S., Valkenberg, P. M., & Peter, J. (2009). Development and Validation of a Game Addiction Scale for Adolescents. *Media Psychology, 12*(1), 77-95.

Leunissen, I., Zandbelt, B. B., Potocanac, Z., Swinnen, S. P., & Coxon, J. P. (2017). Reliable estimation of inhibitory efficiency: to anticipate, choose or simply react? *European Journal of Neuroscience*, *45*(12), 1512–1523. https://doi.org/10.1111/ejn.13590

Limongi, R., Bohaterewicz, B., Nowicka, M., Plewka, A., & Friston, K. J. (2018). Knowing when to stop: Aberrant precision and evidence accumulation in schizophrenia. *Schizophrenia Research*. https://doi.org/10.1016/j.schres.2017.12.018

Lipszyc, J., & Schachar, R. (2010). Inhibitory control and psychopathology: A meta-analysis of studies using the stop signal task. *Journal of the International Neuropsychological Society*, *16*(6), 1064-1076. doi:10.1017/S1355617710000895

Liu, J., Gao, X. P., Osunde, I., Li, X., Zhou, S. K., Zheng, H. R., & Li, L. J. (2010). Increased regional homogeneity in Internet addiction disorder: A resting state functional magnetic resonance imaging study. *Chinese Medical Journal*, *123*, 1904-1908.

Logan, G. D., & Cowen, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review*, *91*(3), 295–327.

Logan, G. D., Schachar, R. J., & Tannock, R. (1997). Impulsivity and inhibitory control. *Psychological Sciences*, *8*, 60-64.

Logan, G. D., Zandt, T. Van, Verbruggen, F., & Wagenmakers, E.-J. (2014). On the Ability to Inhibit Thought and Action: General and Special Theories of an Act of Control. *Psychological Review*, *121*(1), 66–95. https://doi.org/10.1037/a0035230

Matzke, D., Verbruggen, F., & Logan, G. (in press). The stop-signal paradigm. *Stevens' Handbook of Experimental Psychology and Cognitive Neuroscience, Fourth Edition, Volume Five: Methodology*. John Wiley & Sons, Inc.

Mcdermott, A. F., Bavelier, D., & Green, C. S. (2014). Memory abilities in action video game players. *Computers in Human Behavior*, *34*, 69–78. https://doi.org/10.1016/j.chb.2014.01.018

Muller, D., Judd, C. M., & Yzerbyt, V. Y. (2005). When moderation is mediated and mediation is moderated. *Journal of Personality and Social Psychology*, *89*(6), 852–863. https://doi.org/10.1037/0022-3514.89.6.852

Padmala, S., & Pessoa, L. (2010). Interactions between cognition and motivation during response inhibition. *Neuropsychologia*, *48*(2), 558–565. https://doi.org/10.1016/j.neuropsychologia.2009.10.017

Rey-Mermet, A., Gade, M. (2017). Inhibition in aging: What is persevered? What declines? A meta-analysis. *Psychonomic Bulletin and Review*. Epub.

Rosenberg, B. H., Landsittel, D., & Averch, T. D. (2005). Can video games be used to predict or improve laparoscopic skills? *Journal of Endourology*, *19*, 372-376.

Schachar, R., Tannock, R., Marriott, M., & Logan, G. (1995). Deficient Inhibitory Control in Attention Deficit Hyperactivity Disorder. *Journal of Abnormal Child Psychology*, *23*(4), 411–437.

Slater-Hammel, A. T. (1960) The Reliability, Accuracy and Refractoriness of a Transit Reaction, *Research Quarterly*, *31*(2), 217-28.

Strack, F., & Deutsch, R. (2004). Reflective and impulsive determinants of social behavior. *Personality and Social Psychology Review, 3,* 220-247.

Thorell, L. B., Lindqvist, S., Nutley, S. B., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children.

DevelopmentaL Science, *12*, 106–113. https://doi.org/10.1111/j.1467-7687.2008.00745.x

Unity Technologies SF (2017). Unity Pro (Version 2017.3.1f1). [Software]. Available from http://www.unity3d.com

Van Boxtel, G. J., Van Der Molen, M. W., Jennings, J. R., & Brunia, C. H. (2001). A psychophysiological analysis of inhibitory motor control in the stop-signal paradigm. *Biological Psychology*, *58*, 229–262.

Verbruggen, F., Chambers, C. D., & Logan, G. D. (2013). Fictitious Inhibitory Differences: How Skewness and Slowing Distort the Estimation of Stopping Latencies. *Psychological Review*, *24*(3), 352–362. https://doi.org/10.1177/0956797612457390

Verbruggen, F., & Logan, G. D. (2008). Response inhibition in the stop-signal paradigm. *Trends in Cognitive Science*, *12*(11), 418–424. https://doi.org/10.1016/j.tics.2008.07.005.Response

Volkow, N. D., Fowler, J. S., & Wang, G. J. (2003). The addicted human brain: Insights from imaging studies. *Journal of Clinical Investigation*, *111*, 1444-1451.

Weinbach, N., Kalanthroff, E., Avnit, A., & Henik, A. (2015). Can Arousal Modulate Response Inhibition? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *41*(6), 1873–1877.

Weinstein, A. M. (2010). Computer and Video Game Addiction—A Comparison between Game Users and Non-Game Users. *The American Journal of Drug and Alcohol Abuse*, *36*, 268-276.

Whelan, R., & Garavan, H. (2013). Fractionating the Impulsivity Construct in Adolescence. *Neuropsychopharmacology*, *38*(1), 250–251. https://doi.org/10.1038/npp.2012.175

World Health Organisation. (2018). Gaming Disorder. Retrieved from http://www.who.int/features/qa/gaming-disorder/en/

Yuan, K., Qin, W., Wang, G., Zeng, F., Zhao, L., Yang, X., . . . Tian, J. (2006). Microstructure abnormalities in adolescents with Internet Addiction Disorder. *PLoS ONE* (Vol. 6).

Appendix A

ID	Game 1	Game 2	Game 3	0-3 months	3-6 months	6-9 months	9-12 months	Sex	Age	Functional impulsivity	Dysfunctional Impulsivity
1	Nil	Nil	Nil	0	0	0	0	M	68	5	4
2	Nil	Nil	Nil	0	0	0	0	F	69	4	4
3	Nil	Nil	Nil	0	0	0	0	F	53	4	3
4	The Sims 3	Nil	Nil	0	0	8	10	F	19	9	9
5	Piccolo	Words with friends	Nil	1	0	0	0	F	25	6	6
6	Sudoku	Yu-Gi-Oh	Words with friends	2	2	2	4	M	24	7	7
7	Heroes of the Storm	Skyrim	Zero-K	30	30	30	30	M	29	7	5
8	God of War	Path of Exile	Rocket League	25	20	20	20	M	24	5	4
9	Temple Run	Wood Puzzle	Nil	0	0	3	0	F	22	3	4
10	League of Legends	God of War	Bloodborne	40	40	25	20	M	22	5	5
11	Player Unknowns Battlegrounds	League of Legends	Fortnite	40	40	30	30	M	19	6	6
12	Player Unknowns Battlegrounds	Civilisation VI	Overwatch	20	20	20	10	M	25	4	4
13	Nil	Nil	Nil	0	0	0	0	F	20	5	4
14	World of Warcraft	Heroes of the Storm	Star Wars: Galaxy of Heroes	50	65	50	65	M	25	4	4
15	Mordheim	Age of Empires III	Fallout	8	40	5	5	M	21	6	7
16	Pokemon Go	Crash Bandicoot	Words with friends	20	15	10	8	M	25	4	8
17	Persona 5	Legend of Zelda	League of Legends	7	9	10	7	M	25	6	3
18	Dark Souls: Remastered	Dark Souls 3	Legend of Zelda	20	15	5	13	M	24	5	3
19	Assassins Creed	Sniper Elite	Deadpool	12	10	8	12	M	20	5	4
20	Candy Crush	8 Pools	Nil	0	0	0	0	F	22	10	8
21	Overwatch	Player Unknowns Battlegrounds	Metal Gear Solid V	35	35	25	15	M	30	8	6
22	Skyrim	Love Nikki	Destiny	10	50	30	40	F	18	5	8
23	Rocket League	Clash Royal	Fallout 4	40	36	30	20	M	20	5	6
24	Overwatch	Call of Duty	Player Unknowns Battlegrounds	20	16	16	50	M	25	7	7
25	Fifa	Ratchet and Clank	Nil	10	10	7	12	M	25	5	4
26	Company of Heroes	Skyrim	Left for Dead	5	4	3	3	M	21	8	6
27	Perimeter	Defence Grid 2	Battlefield: Bad Company	10	10	10	10	M	58	4	3
28	Call of Duty	Mario	Starwars: Battlefront	5	3	3	3	F	19	10	4
29	Player Unknowns Battlegrounds	Left for Dead	Nil	12	6	1	1	M	25	8	5
30	Nil	Nil	Nil	0	0	0	0	F	60	4	4
31	Yakuza 6	X-Com 2	Megadimension Neptunia VIIR	40	30	20	30	M	30	4	4
32	Fifa	Nil	Nil	5	2	0	0	M	30	8	4
33	Mario Cart 8	Fortnite	Nil	8	4	0	3	F	22	6	5
34	Nil	Nil	Nil	0	0	0	0	M	41	3	4
35	Overwatch	Story of Season: Trio of Towns	Terraria	25	30	30	30	F	26	5	3
36	Player Unknowns Battlegrounds	Overwatch	League of Legends	30	30	30	10	M	23	7	4
37	Dirty Bomb	Terraria	Minecraft	32	32	10	27	M	21	7	9
38	Nil	Nil	Nil	0	0	0	0	F	19	7	4
								Mean age	28.78947		
								SD	13.79808		

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Appendix B

Game	AR Score	ARI Score	Total		Scores	AR
Nil	None	None	0		None	0
8 Pools	None	None	0		Low	1
Age of Empires III	None	None	0		High	2
Assassins Creed	High	High	4			
Battlefield: Bad Company	High	High	4			
Bloodborne	High	High	4			
Call of Duty	High	High	4			
Candy Crush	None	None	0			
Civilisation VI	None	None	0			
Clash Royal	Low	None	1			
Company of Heroes	High	Low	3			
Crash Bandicoot	High	High	4			
Dark Souls: Remastered	High	High	4			
Dark Souls 3	High	High	4			
Deadpool	High	Low	3			
Defence Grid 2	Low	Low	2			
Destiny	High	High	4			
Dirty Bomb	High	High	4			
Fallout	None	None	0			
Fallout 4	High	High	4			
Fifa	High	High	4			
Fortnite	High	High	4			
God of War	High	High	4			
Heroes of the Storm	High	High	4			
League of Legends	High	High	4			
Left for Dead	High	High	4			
Legend of Zelda	High	Low	3			
Love Nikki	None	None	0			
Mario	High	High	4			
Mario Cart 8	High	High	4			
Megadimension Neptunia VIIR	High	Low	3			
Metal Gear Solid V	High	High	4			
Minecraft	High	Low	3			
Mordheim	None	None	0			
Overwatch	High	High	4			
Path of Exile	High	High	4			
Perimeter	Low	None	1			
Persona 5	Low	None	1			
Piccolo	None	None	0			
Player Unknowns Battlegrounds	High	High	4			
Pokemon Go	Low	None	1			
Ratchet and Clank	High	High	4			
Rocket League	High	High	4			
The Sims 3	Low	None	1			
Skyrim	High	High	4			
Sniper Elite	High	High	4			
Star Wars: Galaxy of Heroes	None	None	0			
Starwars: Battlefront	High	High	4			
Story of Season: Trio of Towns	Low	None	1			
Sudoku	None	None	0			
Temple Run	High	High	4			
Terraria	High	High	4			
Wood Puzzle	None	None	0			
Words with Friends	None	None	0			
World of Warcraft	High	High	4			
X-Com 2	None	None	0			
Yakuza 6	High	High	4			
Yu-Gi-Oh	None	None	0			
Zero-K	Low	None	1			

Appendix C

ID	Gaming H	Gaming Score	FINAL NUMBER
1	0	0	0
2	0	0	0
3	0	0	0
4	234	1	234
5	13	0	0
6	130	0	0
7	1560	9	14040
8	1105	12	13260
9	39	4	156
10	1625	12	19500
11	1820	12	21840
12	910	8	7280
13	0	0	0
14	2990	8	23920
15	754	0	0
16	689	5	3445
17	429	8	3432
18	689	11	7579
19	546	11	6006
20	0	0	0
21	1430	12	17160
22	1690	8	13520
23	1638	9	14742
24	1326	12	15912
25	507	8	4056
26	195	11	2145
27	520	7	3640
28	182	12	2184
29	260	8	2080
30	0	0	0
31	1560	7	10920
32	91	4	364
33	195	8	1560
34	0	0	0
35	1495	9	13455
36	1300	12	15600
37	1313	11	14443
38	0	0	0

Appendix D

Please read the following statements and tick the box that you feel most applies to you

		True	**False**
1	I don't like to make decisions quickly, even simple decisions, such as choosing what to wear, or what to have for dinner		
2	I will often say whatever comes into my head without thinking first		
3	I am good at taking advantage of unexpected opportunities, where you have to do something immediately, or you lose your chance		
4	I enjoy working out problems slowly and carefully		
5	I am uncomfortable when I have to make up my mind rapidly		
6	I frequently make appointments without thinking about whether I will be able to keep them		
7	I like to take part in really fast paced conversations, where you do not have much time to think before you speak		
8	I frequently buy things without thinking about whether or not I can really afford them		
9	Most of the time, I can put my thoughts into words very rapidly		

10	I often make up my mind without taking the time to consider the situation from all angles		
11	I don't like to do things quickly, even when I am doing something that is not very difficult		
12	Often, I do not spend enough time thinking over a situation before I act		
13	I would enjoy working at a job that required me to make a lot of split-second decisions		
14	I often get into trouble because I do not think before I act		
15	I like sports and games in which you have to choose your next move very quickly		
16	Many times, the plans I make don't work out because I haven't gone over them carefully enough in advance		
17	People have admired me because I can think quickly		
	Continued on next page.		
18	I rarely get involved in projects without first considering the potential problems		
19	I have often missed out on opportunities because I couldn't make my mind up fast enough		
20	Before making any important decisions, I carefully weigh the pros and cons		
21	I try to avoid activities where you have to act without much time to think first		
22	I am good at careful reasoning		

23	I often say and do things without considering the consequences		

Appendix E

Videogame experience questionnaire

Age: Sex:

In the last 12 months please list the top three video games you have spent the most time playing. If you have only played one or two games, please list them anyways. If you have not played any, please write ‘Nil’.

The timeline provided dates back 12 months. Each interval represents three (3) months. At each interval please list, on average, how many hours a week you played videogames. Please ask the investigator to assist you if you are unclear on these instructions.

12months__________9months__________6months__________3months__________Now

Appendix F

Appendix G

The Pearson's product-moment correlation analyses revealed no significant association between gaming experience and FI, *r*(36)=-0.06, *p*=.706, or DI, *r*(36)=0.09, *p*=.582. There was also no significant association between FI and mean SSRT, *r*(36)=0.07, *p*=.697, FI and integrated SSRT, *r*(36)=0.17, *p*=.320, DI and mean SSRT, *r*(36)=0.19, *p*=.244 or DI and integrated SSRT (36)*r*=0.23, *p*=.163. As there was no significant relationship between the possible mediators (functional and dysfunctional impulsivity) and the outcome and predictor variables, illustrated in *Figure 1*, there was no mediation (Baron & Kenny, 1986). There was also no significant relationship between gaming experience and SSRT calculated with the integrated method, *r*(36)=-0.43, *p*=.007, however, there was a significant relationship between gaming experience and SSRT calculated with the mean method, *r*(36)=-0.49, *p*=.002. This evidences that as gaming experience increase, SSRTs decrease—becoming faster. Bias and precision scores across the two sessions were regressed on gaming experience. An association between gaming experience and bias was not found in the first session, *r*(36)=-0.21, *p*=.205, nor the second, *r*(36)=-0.07, *p*=.691. The same was found for precision—there was no significant association in the first session, *r*(36)=-0.18, *p*=.278, nor the second, *r*(36)=-0.03, *p*=.850. However, because there was no evident difference, I ran two follow up ANOVAs to investigate if there was a learning effect. The first BlockXBias ANOVA revealed no significant main effect of block, *F*(37, 185)=2.00, *p*=.145, following a Greenhouse-Geisser adjustment. The second BlockXPrecision ANOVA, did, however, reveal a significant main effect of block, *F*(37, 185)=3.79, *p*=.019, following a Greenhouse-Geisser adjustment.

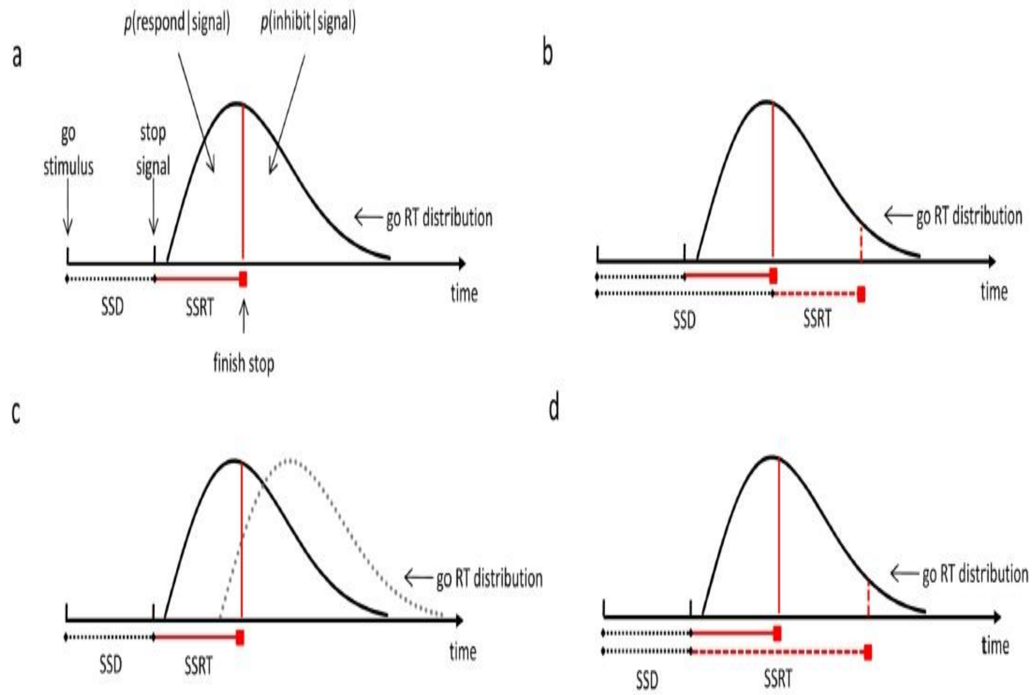

Figure 1. Assumptions of the horse-race model. (a) Graphical representation of the assumptions of the independent race model A graphical representation of the assumptions of the independent horse race model highlighting how probability of responding [p(respond|signal)] and the probability of stopping [p(inhibit|signal)] both depend upon stop-signal delay (SSD). (b) go reaction time distribution (c) stop-signal reaction time (SSRT) distribution (d) . P(respond|signal) is represented by the area under the curve to the left of each red vertical line and the probability of inhibiting [p(inhibit|signal)] by the area under the curve to right of the line. Retrieved from "Response inhibition in the stop-signal paradigm" by Verbruggen & Logan, 2008, *Trends in Cognitive Sciences*, *12*(11), p. 422. Copyright 2008 by the US National Library of Medicine.

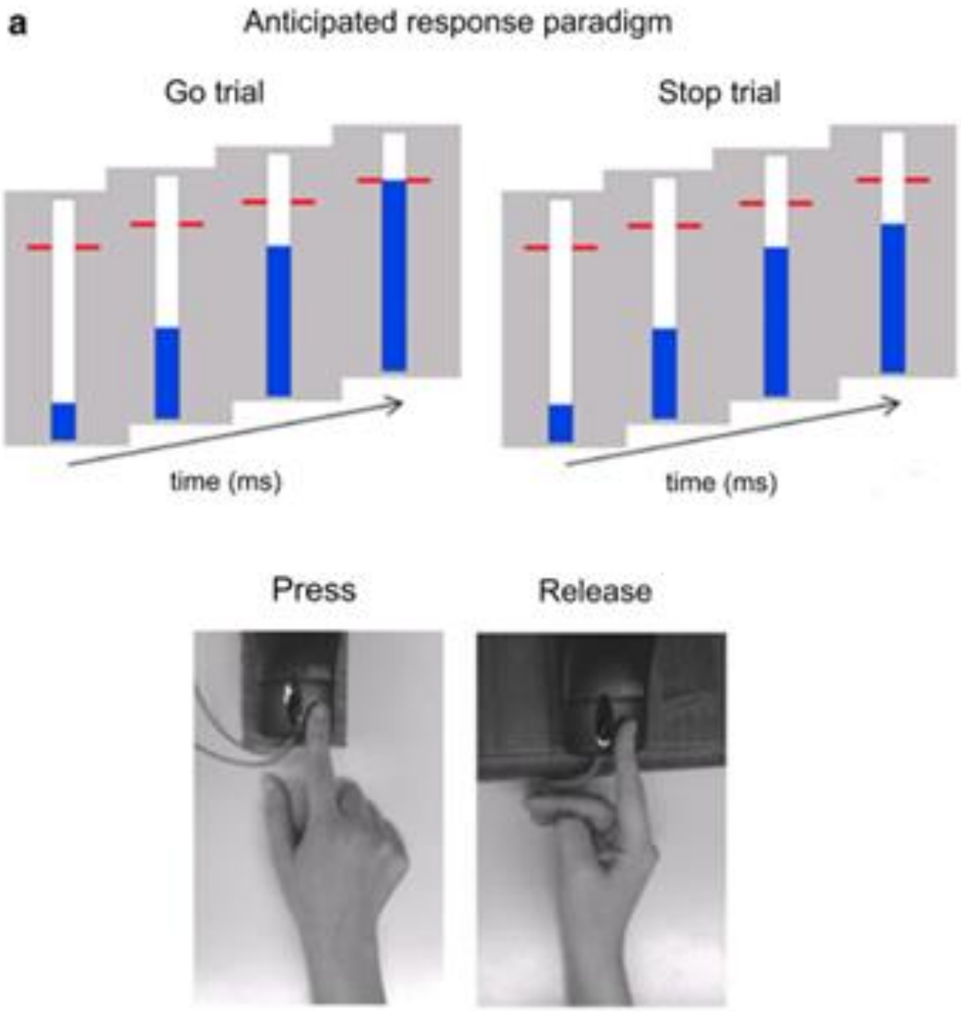

Figure 2. A graphical representation of an anticipatory response task. The blue bar rises at a constant velocity and participants are required to stop it as accurately as possible at the red line. Should the bar turn from blue to red, they are required to withhold their response. Retrieved from "Reliable estimation of inhibitory efficiency: to anticipate, choose or simply react?" by Leuniessen, Zandbelt, Potocanac, Swinnen and Coxon, 2017, European Journal of Neuroscience, 45, p. 1513. Copyright 2017 by the Federation of European Neurosciences and John Wiley & Sons Ltd.

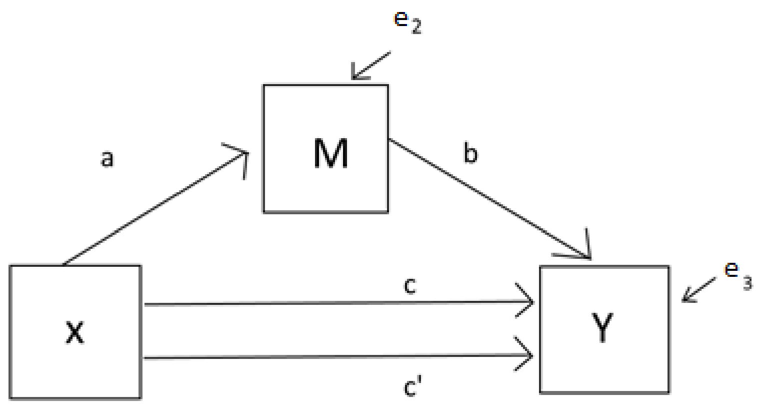

Figure 3. The single mediator model. X is the independent variable, M is the mediating variable and Y is the dependent variable. The coefficient, c, represents the overall effect of X on Y; c’ represents the X-Y relationship while controlling for M; a represents the relationship between the independent variable and the mediator; and b represents the relationship between the mediator and the dependent variable while controlling for the X-M relationship. Error in measurement is represented by e.

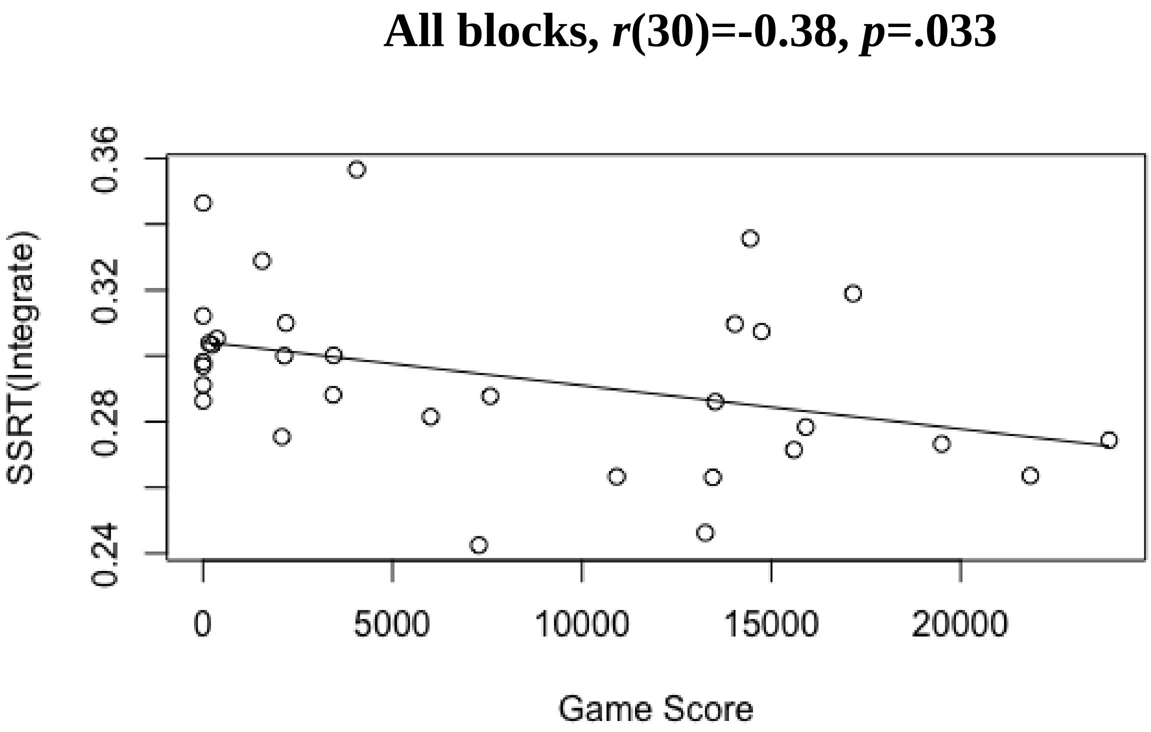

Figure 4. The negative correlation between gaming experience (x axis) and SSRT calculated with the integrated method (y axis) in block 1. This indicates that as gaming score increases, SSRT decreases (improves).

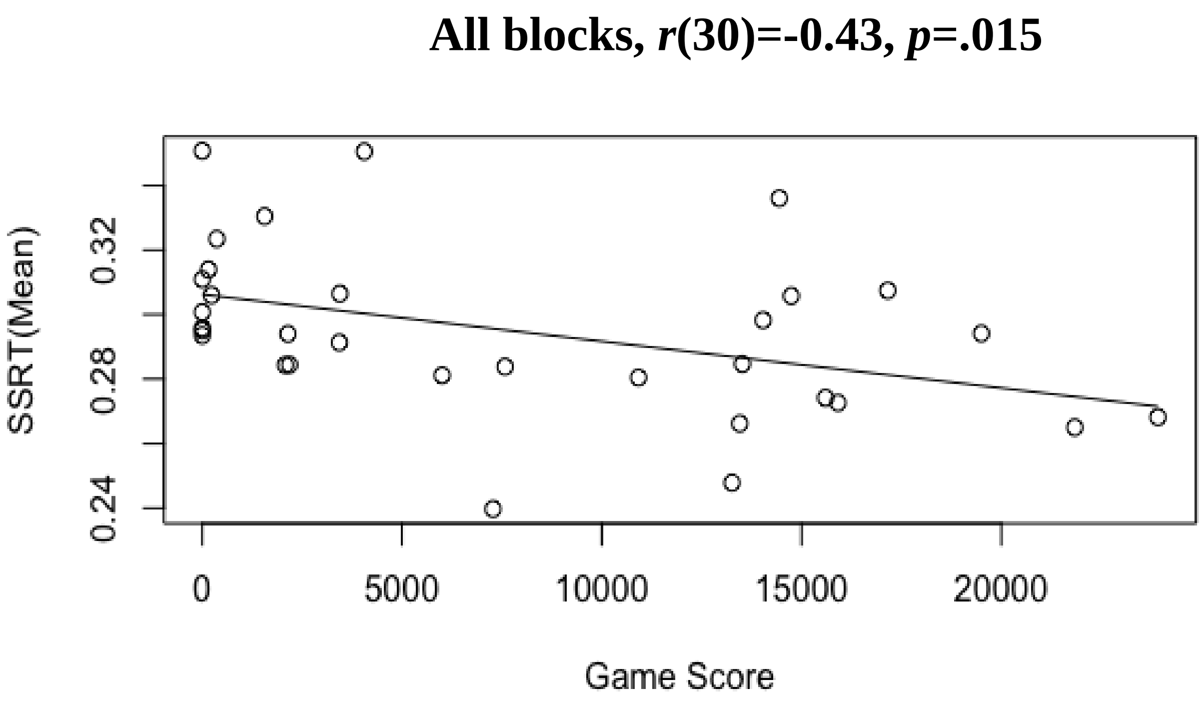

Figure 5. The negative correlation between gaming experience (x axis) and SSRT calculated with the mean method (y axis) in block 1. This indicates that as gaming score increases, SSRT decreases (improves).

All blocks, *r*(30)=-0.35, *p*=.046

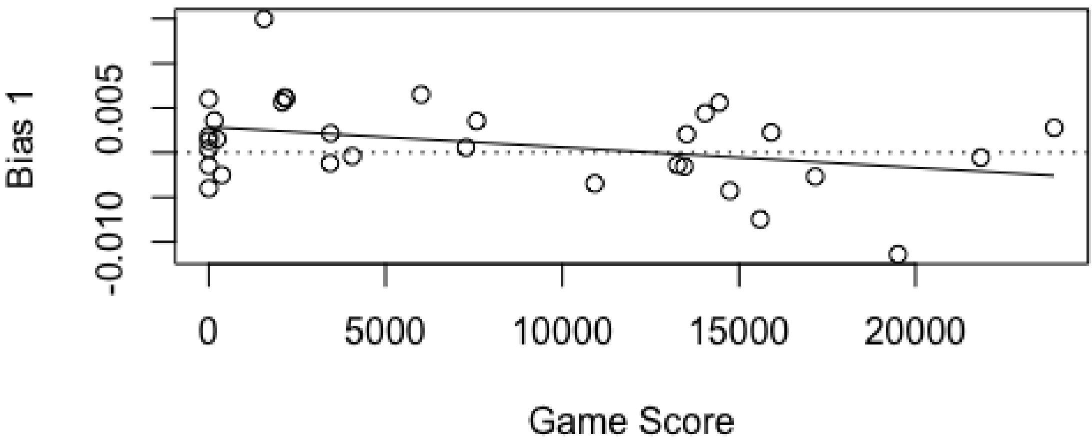

Figure 6. The negative correlation between gaming experience (x axis) and bias scores (y axis) in session 1. The dotted line represents 0 bias which means perfect responding. The line of best fit crosses 0 indicating that the significant correlation does not infer any interpretable relationship between gaming experience and bias scores.

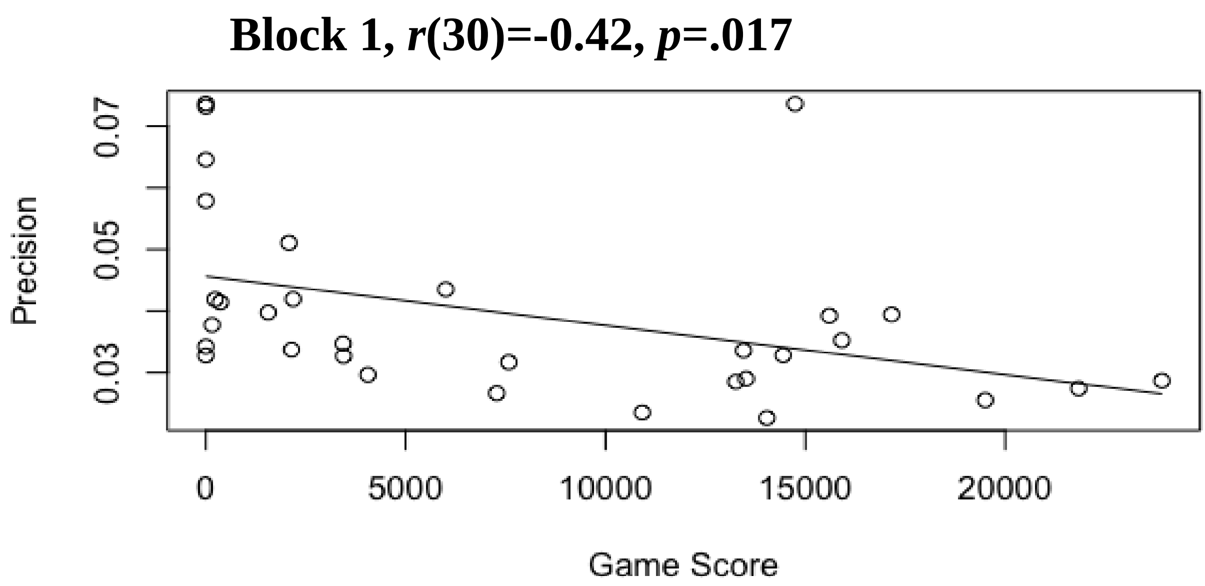

Figure 7. The negative correlation between gaming experience (x axis) and precision scores (SD of mean RT; y axis) in block 1. This indicates that as gaming score increases, precision decreases (improves).

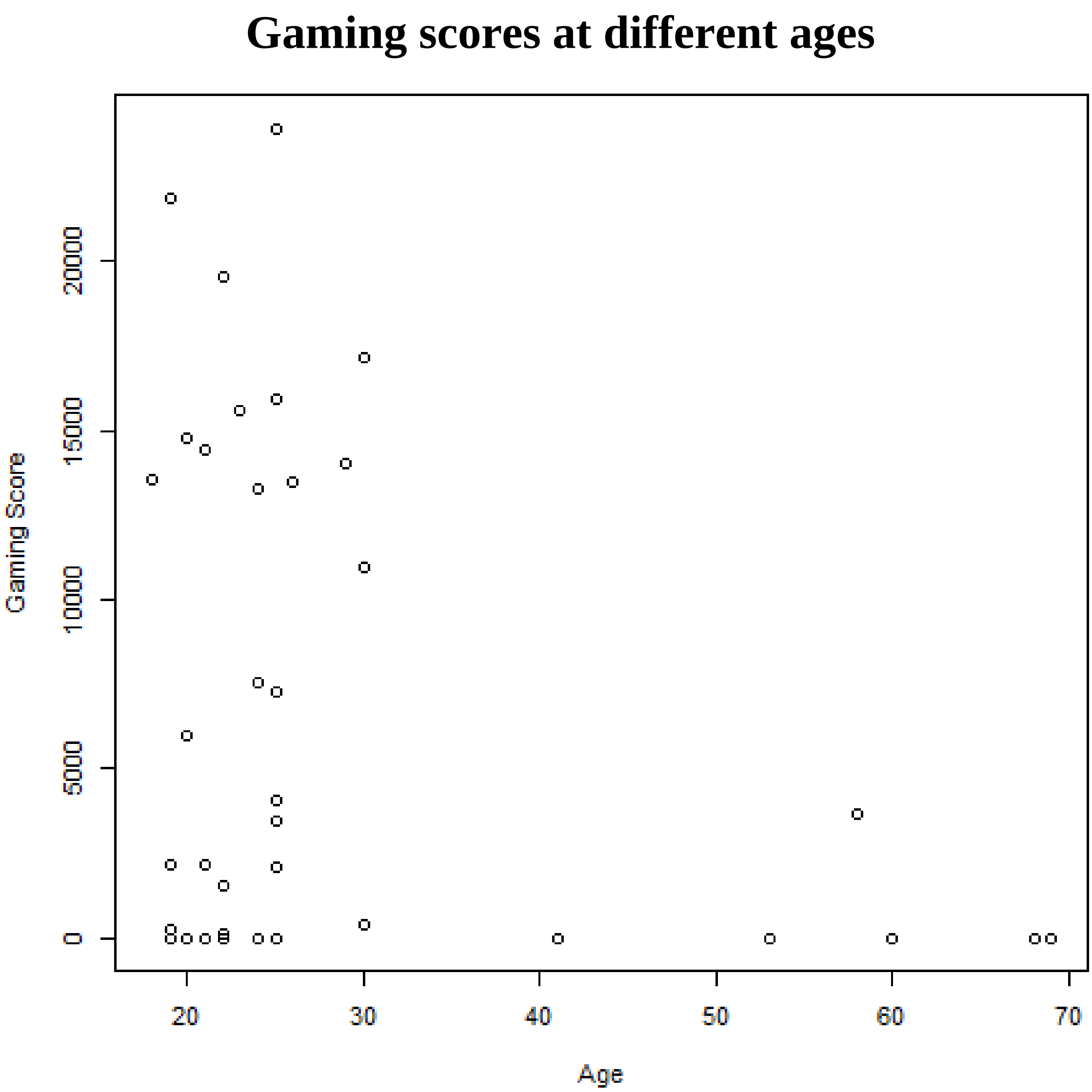

Figure 8. A representation of the distribution of videogame experience across different ages. Those who were above 40 had little to none gaming experience and could have potentially confounded the analyses.